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WEIGHTLESSNESS SIMULATION USING WATER IMMERSION TECHNIQUES: AN ANNOTATED BIBLIOGRAPHY

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A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA

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ABSTRACT

This compilation contains 97 selected references pertaining to biomedical and behavioral research involving immersion of human subjects. The references are organized under three principal topics: (1) Physiological Studies, including acceleration, impact protection and physiological responses to weightlessness simulations, (2) Human Engineering Studies, and (3) Techniques and Personal Equipment Requirements for immersion studies.

The references are arranged alphabetically by author or title under each separate topic. An Author Index is included as an aid in locating specific investigators and publications.

The references cited are considered to be the principal contributions to the literature during the period from 1951 through July 1965, including both open and government sources.

NOTICE

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PREFACE

This bibliography was compiled as part of a study to determine the desirability of developing a weightlessness simulation capability for Lockheed Missiles & Space Company using water immersion techniques.

During the past fifteen years immersion techniques have been used to investigate the physiological and psychological responses of human subjects to a particular set of environmental stresses associated with aerospace flight.

Those studies of particular interest have been concerned with acceleration and impact protection afforded by immersion, and with the effects of prolonged exposure to the free fall conditions of orbital flight on human structures, organ systems and task performance.

The techniques used and the results of research abstracted in this report are related to the design, development and evaluation of manned spacecraft and re-entry vehicles, flight crew protective equipment, work places, locomotion aids and restraint devices, procedures for performing crew tasks and countermeasures for minimizing the debilitating effects of prolonged weightlessness. Certain references are also applicable to current studies of ocean systems and of man's capabilities to perform useful work under the sea.

The references cited are considered to be the principal contributions to the literature during the period from 1951 through July 1965.

The literature was compiled by Helen M. Abbott, Research Information Analyst, Technical Information Center and the evaluation of the literature was made by John H. Duddy, Senior Engineering Psychologist, Manned Space Programs.

LITERATURE SEARCH CAPABILITY DEFINED

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PART I: PHYSIOLOGICAL STUDIES

A. Acceleration Stress Tolerance

1. Beckman, E. L., R. M. Chambers, et al
PHYSIOLOGIC CHANGES OBSERVED IN HUMAN SUBJECTS DURING ZERO G SIMULATION BY IMMERSION IN WATER UP TO NECK LEVEL. Aerospace Medicine 32(11): 1031–1041, 1961.

To ascertain some of the effects of prolonged weightlessness on man, a series of experiments involving seven Ss immersed in water (an effective simulation of the weightless state with respect to proprioceptive responses) up to the neck level for periods of 5 to 23 hours was conducted. Weight changes on a tracking task, during exposure to a simulated space vehicle re-entry deceleration profile, attributable to water immersion were determined. Changes in tolerance to accelerative forces were also measured.

2. Benson, V. G., E. L. Beckman, et al
EFFECTS OF WEIGHTLESSNESS AS SIMULATED BY TOTAL BODY IMMERSION UPON HUMAN RESPONSE TO POSITIVE ACCELERATION. Naval Air Development Ctr., Johnsville, Pa. Rept. No. NADC-MA-6132. AD 262 329. See also Aerospace Medicine 33(2): 198–203, Feb 1962.

Twelve members of Underwater Demolition Team No. 21 used underwater breathing equipment while completely immersed in water for 18 hours. Their response to positive acceleration was determined by observing the G level at which the limitation of ocular motility under acceleration (LOMA) occurred. This G level is approximately the same as when loss of peripheral vision or greyout occurs when subjects are exposed to positive acceleration. The period of immersion was well-tolerated. A small but statistically significant decrease in the G level at which LOMA occurred was found following the period of immersion.

(see also references 9, 90)

3. Benson, V. G., E. L. Beckman, et al
WEIGHTLESSNESS SIMULATION BY TOTAL BODY IMMERSION. PHYSIOLOGICAL EFFECTS.
Naval Air Development Ctr., Johnsville, Pa.
Report No. NADC-MA-6134. AD-263 194, 1961.

Attempts have been made to simulate the weightless state by immersing subjects in water up to the neck level for varying periods of time. These subjects were exposed to acceleration forces on human centrifuges before and after immersion. A reduction in the ability to withstand these acceleration forces was noted following the immersion period. Immersion in water to the neck level produces a negative pressure breathing situation which in turn results in a profuse diuresis. An attempt was made to eliminate the negative pressure breathing and the diuresis by equipping the subject with a full face diving mask with a compensating regulator and completely immersing him in water for a period of twelve hours. Of the seven subjects tested, only three were able to tolerate the 12-hour period of water immersion. The remaining four terminated early in the study due to the stress of the underwater environment and were not exposed to acceleration forces following their immersion periods.

4. Bondurant, S., W. G. Blanchard, et a
EFFECT OF WATER IMMERSION ON HUMAN TOLERANCE TO FORWARD AND BACKWARD ACCELERATION. Aero Medical Lab., Wright Air Development Center, Wright-Patterson Air Force Base, Ohio. Rept. on Biophysics of Space Flight. Jul 1958, 10p. WADC Technical rept. no. 58-290. AD-155 808.

Accepted physical principles suggest that immersion of subjects in water should constitute effective protection against some of the effects of acceleration. This premise has been evaluated in a study of the duration of tolerance of immersed subjects to forward accelerations of 6 through 14 g. Respiration was maintained by the use of skin diver's breathing equipment. With proper positioning, acceleration time tolerances were observed which were in excessof twice any previously reported.

5. Hardy, J. D.
ACCELERATION PROBLEMS IN SPACE FLIGHT.
IN XXI International Congress of Physiological Science, Buenos Aires, Argentina, Aug 1959.

6. Hyde, Alvin S. and H. W. Raab
A SUMMARY OF HUMAN TOLERANCE TO PROLONGED ACCELERATION. Aerospace Medical Research Lab., Air Force Systems Command, Wright-Patterson AFB, Ohio. Rept. No. AMRL-TR-65-36. Final Report Jan 1963 – Jan 1965.

Human subject tolerance to accelerations of greater than one second duration is summarized for the orthogonal X, Y, and Z axes. Because each investigator at each laboratory utilizes different restraint systems, body positions, ambient temperatures, etc. and most important, utilizes different criteria of "tolerance," the data are referenced and presented in tables and graphs for each major category (direction of acceleration. The points presented in the graphs and tables are usually the highest values achieved; in each series there were subjects who could not tolerate the given direction, amplitude, and duration.

7. Margaria, R., T. Gualtierotti, and D. Spinelli
PROTECTION AGAINST ACCELERATION FORCES IN ANIMALS BY IMMERSION IN WATER. J. of Aviation Medicine 29(6): 433 – 437, Jun 1958.

Experimentally an animal immersed in water can stand acceleration forces more than ten times greater than in air, the probability of survival being very high even at 1,000 G. A limit to the resistance to acceleration forces is given by parts of the body having a specific weight different from that of the rest of the body, particularly the lungs for their air content, and the otoliths, Rat foetuses, having no air in their lungs, can survive impacts corresponding to accelerations higher than 10,000 G when the mother is floating in water.

8. Thiede, F. C., C. F. Lombard, and S. Davis Bronson
EFFECTS OF IMPACT ACCELERATION ON GUINEA PIGS PROTECTED BY A FLUID-FILLED BLADDER DEVICE AND BY TOTAL WATER IMMERSION. Aerospace Medicine, 1057 – 1062, Nov 1964.

Impact acceleration pathology in guinea pigs at 50 g, positioned either footward or transverse supine 12.5° from the horizontal, was not significantly different whether protection was afforded by full fluid immersion, a limit-stretch fluid-filled bladder or a fully contoured container. Intratracheal pressure pulses, however, indicated that intrapulmonic pressure build-up at impact is greater with fluid immersion and container only than with the bladder device. Pathology with 100 g headward acceleration was extensive in the heavier organs with the container-only mode while lung pathology was much more severe in the immersed animals oriented footward and headward. This study may offer the same protection to man from impact acceleration as full fluid immersion but with much less weight and without the compression effects on thorax and chest.

PART I: PHYSIOLOGICAL STUDIES

B. Physiological Responses to Simulated Weightlessness

9. Beckman, E. L., K. R. Coburn, et al
SOME PHYSIOLOGICAL CHANGES OBSERVED IN HUMAN SUBJECTS DURING ZERO G SIMULATION BY IMMERSION IN WATER UP TO NECK LEVEL. Naval Air Development Ctr., Johnsville, Pa. Rept. no. NADC MA 6107. AD 256 727, 1961.

Knowledge relative to the effects of prolonged weightlessness is needed in preparing man for space flight. The buoyant force exerted upon immersed bodies effectively simulates the weightless state with respect to proprioceptive sensory responses and perhaps in other ways. An investigation into the physiological effects of immersing subjects in water up to neck level was undertaken. A series of experiments involving 7 subjects immersed in water up to neck level for periods of 5 to 23 hours (5 subjects for 12 hours) showed a significant weight loss during the period of immersion, which was explained by the diuresis which occurred. Pulmonary volume measurements showed a decrease in the expiratory reserve volume and in the respiratory minute volume during immersion. There was no significant decrement in the performance of a tracking task, attributable to the water immersion, during exposure to a simulated space vehicle reentry deceleration profile. Exposure to 4.5 positive G for 15 seconds following water immersion revealed a decrement in tolerance in most subjects.

10. Benedikt, E. T., (ed.)
WEIGHTLESSNESS – PHYSICAL PHENOMENA AND BIOLOGICAL EFFECTS. New York: Plenum Press, 1961.

Contents include:
Levine, R. B. "Zero Gravity Simulation," pp. 135–153
Simons, J. C. "Current WADD Weightless Research"
Brown, E. L. "Human Performance and Behavior During Zero Gravity"

(see also references 1, 3, 70, 91)

11. Bourne, Geoffrey H.
(Emory University, Dept. of Anatomy, Atlanta, Ga.)
NEUROMUSCULAR ASPECTS OF SPACE TRAVEL. IN: Physiology of Man in Space. New York, Academic Press, Inc., 1963, pp. 1 – 59.

Discussion of the muscular stresses in space flight resulting from weightlessness and high-g conditions. Radiation effects are also briefly noted. The macroscopic and microscopic structures of muscles and their methods of action and innervation are studied. The responses of sense organs to subgravity are tabulated. Illustrated are short-term water-immersion tanks, related equipment, and other zero-gravity simulators.

12. Bowers, J. A., W. B. Hood, et al
HEMODYNAMIC EFFECTS OF WATER IMMERSION. Aerospace Medical Research Lab. and Indiana Univ. Cardiopulmonary Lab. AMRL, Wright-Patterson AFB, Ohio. Paper given at Aerospace Med. Assoc. 36th Annual Meeting, Apr 1965, N. Y.

Five Air Force volunteers were studied during two separate eight-hour periods of supine water immersion and supine bed rest for changes in heart rate, blood pressure, and cardiac output (indicator dilution curves), and for alterations in blood volume (Evans Blue), urine volume and osmolarity. A dry suit with a free-breathing helmet was used for immersion. Blood sampling and measurement of hemodynamic variables utilized indwelling arterial and superior vena cava catheters. In an attempt to evaluate cardiovascular deconditioning, the hemodynamic responses to 60° head up tilt, Valsalva, and venous occlusion cuffs were also studied pre- and post-immersion and bed rest. Immersion, compared with bed rest in the same subject, produced a consistent increase in urine volume (range, 173–670 per cent) with a fall in the ratio of urine to plasma osmolarity. These changes during immersion were accompanied by a decrease in plasma volume (range, –520 to – 1085 cc), slight increase in plasma osmolarity (range, 7 to 12 milliosmoles/L), and minimal increases in blood hemoglobin (range, 0.1 to 2.0 gms/%). There were no consistant changes in blood pressure, cardiac output, or heart rate during water immersion or bed rest. Clear-cut evidence of cardiovascular deconditioning was not observed. Comparable changes in blood pressure, heart rate, and cardiac output occurred both pre- and post-immersion and bed rest in response to tilt, Valsalva, or venous occlusion cuffs.

13. Brown, J. L.
ORIENTATION TO THE VERTICAL DURING WATER IMMERSION. J. Aerospace Medicine 32:209–217, Mar 1961.

Subjects were immersed in water at a depth of either 18 or 25 feet and then rotated in a tucked position on a rod through 3, 4, or 5 revolutions. Rotation was terminated with the head in one of 4 positions: upright, inclined forward, down, or back. Upon termination of rotation subjects were directed to point in the up direction, then to nod the head and correct the direction of pointing if necessary, and finally to swim toward the surface. There were errors in direction of initial pointing of as much as 180 degrees. Errors were greatest with the head down or back and least with the head up or forward. Nodding of the head was followed by consistent improvement in the direction of pointing. There was little indication of any difficulty in swimming in the upward direction. Greater density of the legs as compared to the trunk resulted in fairly rapid vertical orientation of the body upon release of the rod. The results are interpreted to reflect the relative inefficiency of the utricles as gravity sensors when the head is in certain positions. The simulation of zero gravity may be enhanced by utilizing these positions with water immersion.

14. Campbell, P. A. and S. J. Gerathewohl
THE PRESENT STATUS OF THE PROBLEMS OF WEIGHTLESSNESS. Texas State Journal of Medicine 55(4):267–274, Apr 1959.

Reports weightless orientation studies made by immersing men in water. Man's ability to orient himself depends upon a variety of factors, and during weightless situations the eye becomes the only reliable organ.

15. Diringshofen von, H.
Immersion in Water as a Partial Simulator of Weightlessness in Space Medicine. Archiv für physikalische Therapie (Leipzig), 14(4): 307–311, Jul – Aug 1962. (In German)

Research on weightlessness employing water-tank type simulators is reviewed in the light of Titov's experience in space flight. Certain disturbances in the physiological functions seen in the experiments were caused by the hydrostatic pressure of the water. A progressive muscular asthenia with increasing tendency to orthostatic collapse developed in the experimental subjects as a direct effect of the hypodynamic environment. This tendency still persisted two days after the seven-day experiment in the water-tank simulator. The lowered stress resistance was evidenced by lowered

acceleration tolerance, lowered physical efficiency in the presence of unimpaired muscle strength, and in particular by lowered sensorimotor performance. The electroencephalogram showed a disturbance in the sleep-wakefulness cycle, i.e., frequent intervals of light sleep or lowered consciousness and only two hours of deep sleep. Recommendations include a program of systematic physical exercise aboard the space ship to maintain muscle and cardiovascular tonus, and training of spatial orientation to compensate for the non-function of the otoliths in zero-gravity conditions.

16. Douglas, William K.
(USAF, Missile Test Center, Patrick AFB, Fla.).
MEDICAL ASPECTS OF ASTRONAUT TRAINING.
IN: Bioastronautics. Edited by Karl E. Schaefer.
New York, Macmillan Co.; London, Collier-Macmillan, Ltd., 1964, pp. 307–313.

Discussion of (1) basic sciences, (2) physical fitness, and (3) conditioning for space flight. It is indicated that the stresses to which the pilot of a spacecraft is exposed are generally similar to more intense than those to which an aircraft pilot is exposed. In order to safeguard the spacecraft pilot from a hostile environment which contains noise, vibration, acceleration, high temperatures, and other stresses, it is thought to be important that he be made intimately aware of the physiology of cardiovascular, respiratory, and vestibular systems. In order to increase the self-reliance of crewmen in the event of illness or incapacity, it may be advisable, according to the author, to give them instruction in diagnostic and therapeutic techniques. The subjects of dietetics and rest, immunizations, basic hygiene, and exercise are discussed, and it is suggested that experience with the use of the Self-Contained Underwater Breathing Apparatus (SCUBA) can help build stamina, give experience in voluntary respiratory control, and, to a degree, simulate weightlessness. Traning devices such as the Multi-Axis Spin Test Inertia Facility (MASTIF) and the centrifuge are discussed and the role of the flight surgeon is outlined.

17. Downey, Vincent M. and Clarence C. Cain
Lockheed Missiles and Space Company,
Sunnyvale, California.
POSSIBLE PHYSIOLOGICAL EFFECTS OF LONG-TERM WEIGHTLESSNESS. Paper given at Aerosp. Med. Assoc. 36th Annual Meeting, Apr 1965, N. Y.

Many unknowns remain in weightlessness. The major questions concern the long-term effects. Fully realizing the possibilities for error, a projection of the possible effects of prolonged weightlessness upon man will nevertheless give us some idea what to expect in future manned orbital flights.

Two sources of such information exist today. The first is the few "hard" data available from the reports of the Mercury and Vostok flights (lasting from one and one-half hours to five days), and the earlier animal suborbital and orbital flights, notably the six-day flight of Laika. These data showed that man can adapt to short-term zero-g exposures. However, extrapolation of the data is a hazardous scientific venture. For example, much of the information obtained from parabolic aircraft flights has been shown to be due to changing or transitional acceleration, rather than to weightlessness itself.

The other source of information at hand is the data from simulation devices. Laboratory experiments in analogues of weightlessness have shown some effects on various organs. All such analogoues are open to question. Conclusions based on these experiments may be in error. It is simply impossible to simulate weightlessness in the laboratory.

Effects on each organ system will be examined separately. The possible effects during long-term exposure to weightlessness will be considered first. Next, the possible effects after exposure to long-term weightlessness will be presented.

18. Gaume, J. G.
THE BIOLOGICAL EFFECTS AND IMPLICATIONS OF WEIGHTLESSNESS. (Martin Company, Denver Division) Apr 1962.

This research report explores the effects and implications of weightlessness on the human body for extended periods. It cites past research on weightlessness and compares bed rest and water suspension with actual weightlessness in outer space. The document suggests carefully planned muscle exercises as a possible means of preventing ill effects caused to the body by long periods of weightlessness.

19. Generales, C. D. J., Jr.
Weightlessness: Its physical, biological, and medical aspects. In MEDICAL AND BIOLOGICAL PROBLEMS OF SPACE FLIGHT: PROCEEDINGS OF A CONFERENCE HELD IN NASSAU, THE BAHAMAS, NOVEMBER 1961. C. H. Bourne, (ed.) N. Y., Academic Press, 1963, pp. 123–187.

General discussion and review of the nature of weightlessness and its effects on biological systems. The geophysical aspects of gravity are considered, as are the gravity environments to be expected on the Moon and various planets. The physiological effects of the weightless environment are considered, including respiratory and cardiovascylar effects in man. The requirements for a life-support system for a space vehicle are studied, including the microorganisms and algae needed, as well

as sources of air and water. Methods of evaluating weightlessness effects are briefly described, including the use of simulators in which a man is immersed in water. Also considered are methods by which the astronaut can accustom himself to the long-term effects of weightlessness. The advantages and disadvantages of the artificial gravity environment are analyzed, and the effects of rotation on man are outlined. The use of weightlessness in surgery is considered in relation to the influence on the body tissues and mechanisms of zero-g.

20. Gerathewohl, S. J.
RECENT EXPERIMENTS ON SUBGRAVITY AND ZERO-G STRESS. (Paper, 31st Annual Meeting, Aerospace Medical Association, May 1960, Miami Beach, Fla.).

Subgravity and zero-G have long been considered an unfavorable environmental condition. For about one decade, several experimenters in this country and abroad have studied the stress as involved in actual and simulated weightlessness on both animals and man. Since weightlessness actually produces a stressless situation, the immersion method has attracted special attention. In this case, no particular surface area has to carry the weight of the body, and the internal stress forces seem to be minimized. Moreover, the remaining stress within the body is isotropic, if the difference in hydrostatic pressure remains small. All this is true within certain limits for the homogenous and non-sensoric part of the organism. Gravity and acceleration changes directly act upon the specific gravireceptors. Stimulation of the vestibular system by angular acceleration will not occur in flight parabolas and orbits, if the subject is at rest, since the rotation of a vehicle around its y-axis does not produce vistibular Coriolis effects. Only rotations of the unrestrained subjects cause extreme disorientation after a few revolutions which, in fact, border on severe cases of vertigo, at times. However, with a visual frame of reference and experience in unrestrained floating, moving, and performing, the weightless condition does not appear to be a serious obstacle to space flight.

21. Gerathewohl, S. J. and J. E. Ward
PSYCHOPHYSIOLOGIC AND MEDICAL STUDIES OF WEIGHTLESSNESS. Physics and Medicine of the Atmosphere and Space. (Proceedings of the Second International Symposium on the Physics and Medicine of the Atmosphere and Space, held at San Antonio, Texas, November 10, 11, and 12, 1959, sponsored by the School of Aviation Medicine, Aerospace Medical Center (ATC) Brooks AFB, Texas). (New York: John Wiley & Sons, 1960). Chapter 26, pp. 422–434.

Reports study of group of 46 men and one woman for weightlessness tolerance at the USAF School of Aviation Medicine. Tabular account of results with psychological reactions.

22. Force Fields
In: NASA Life Sciences Data Book (National Aeronautics and Space Administration, Washington, D. C.) (Contract NASr-89.) Jun 1962.

This handbook provides 28 pages of charts and summaries from the various force fields. Areas covered include: acceleration (experience, impact, transverse G limits, acceleration terminology, variations in G tolerance, G vector and consciousness, direction of force, maximum tolerable acceleration profiles, G protection by water immersion); tolerance to tumbling; deceleration (abrupt transverse, positive and negative G decelerations, tolerance to vertical impact, human impact sensitivity, impact tolerance); G fields in rotating space vehicles; vibration, (response, tolerances, physiological effects, psychophysical factors, performance functions, transmission, oxygen consumption, respiratory ventilation, and tracking performance); resonance of the abdominal wall; oscillations; high dynamic pressures; and blast injury.

23. Giovanni, Cleto Di, Jr. and Randall M. Chambers
PHYSIOLOGIC AND PSYCHOLOGIC ASPECTS OF THE GRAVITY SPECTRUM. New England Journal of Medicine, 270: 134–139, Jan 16, 1964.

A discussion is presented of the possible physiologic and psychologic effects of subgravity and weightlessness. Problems considered include excess calcium mobilization,

muscular atrophy, and bone demineralization; disorientation, the oculogravic illusion, and vestibular disturbances; psychomotor performance, visual acuity, and sleep; and orthostatic intolerance. Pertinent evidence is presented from laboratory experiments, zero-gravity trajectory flights, and suborbital and orbital flights.

24. Giovanni, Cleto Di, Jr. and Randall M. Chambers
PHYSIOLOGIC AND PSYCHOLOGIC ASPECTS OF THE GRAVITY SPECTRUM. New England Journal of Medicine, 270: 88–94, Jan 9, 1964.

A discussion is presented of the possible effects of acceleration on psychomotor performance, and the effects of subgravity and weightlessness on the cardiovascular system. Pertinent data are presented from laboratory and clinical experiments and orbital flights. The human centrifuge is described, and techniques for the study of weightlessness are discussed, including the Keplerian trajectory, orbital flight, bed rest, and water immersion.

25. Giovanni, Cleto Di and Randall M. Chambers
PSYCHOPHYSIOLOGICAL ASPECTS OF REDUCED GRAVITY FIELDS, REPORT NO. 6. Naval Air Development Center, Johnsville, Pa. Aviation Medical Acceleration Lab. Rept. no. (NADC-MA-6305; AD-430095), N64-15753, 30 Dec 1963.

Considerable data have been collected concerning acceleration physiology from centrifuge, rocket sled, and drop tower studies but weightlessness has remained a poorly understood environment primarily because there is no way to duplicate it on earth. This report considers the various methods used to study or approximate the subgravity state, and the results and extrapolations that have been drawn from them. The cardiovascular and musculoskeletal aspects of recent bed-rest and water-immersion studies are examined, and results are compared with the data from actual space flights. Real weightlessness apparently has been an innocuous environment thus far, and the only factor of concern has been a tendency toward postural hypotension detected immediately following recovery after missions of 9 and 34 hours. As longer missions are achieved, other problems, such as muscle atrophy and excessive calcium mobilization, may appear.

26. Goodall, McC., Michael McCally, and Duane E. Graveline
URINARY ADRENALINE AND NORADRENALINE RESPONSE TO SIMULATED WEIGHTLESS STATE.
American Journal of Physiology, 206: 431–436, Feb 1964. (Contract No. AF-33(657)-10627.)

Sixteen normal subjects were placed in a simulated weightless state, i.e., water immersion. After 6 hours of immersion, urine samples were collected and bio-assayed for adrenaline and noradrenaline. The excretion of adrenaline was moderately increase ($P < 0.15 > 0.10$), possibly related to the anxiety associated with the immersion. The excretion of noradrenaline was significantly ($P < 0.01$) reduced during immersion. Six subjects were also studied during passive vertical tilt following the immersion. The increase in pulse rate and decrease in pulse pressure were significantly greater than those observed during a control tilt. The results of these experiments indicate that the decrease in orthostatic tolerance following a simulated weightless state is probably related to a decrease in sympathetic nerve activity, which in turn is reflected by a decline in the urinary output of the sympathetic neurohormone noradrenaline.

27. Gooden, B. A.
Bio-medical problems of prolonged spaceflight.
SPACEFLIGHT, 7(3): 98–103, May 1965.

The problems affecting the cardiovascular system is discussed and some methods are suggested for protecting astronauts during and after long space missions. Experimental procedures are noted for producing cardiovascular deconditioning in subjects on earth.

28. Graveline, D. E.
EFFECTS OF POSTURE ON CARDIOVASCULAR CHANGES INDUCED BY PROLONGED WATER IMMERSION. Rept. for Mar–May 61, on Biophysics of Flight. (Aerospace Medical Lab., Aeronautical Systems Div., Wright-Patterson AFB, Ohio).
ASD TR 61-563, Oct 1961. Ad-270 869.

Previous hypodynamic research using water-immersion techniques was done with the subjects in a semi-reclining position. To evaluate the possible influences of posture and negative immobilization on the cardiovascular deterioration associated with prolonged water immersion, a technique was employed which allowed complete freedom of activity, position, and attitude. Five subjects were evaluated for functional change

after 6 hours in this environment. The results indicate that postural factors play an insignificant role in the mechanism of cardiovascular alteration induced by water immersion.

29. Graveline, Duane E.
MAINTENANCE OF CARDIOVASCULAR ADAPTABILITY DURING PROLONGED WEIGHTLESSNESS. Aeronautical Systems Div., Biomedical Lab., Wright-Patterson AFB, Ohio. Rept. no. ASD TR-61-707, Dec 1961 (Project 7222; Task 722201).

During prolonged zero gravity because of the absence of hydrostatic pressure influences, special techniques will be necessary to maintain cardiovascular adaptability and provide the orbiting astronaut with optimum tolerance for reentry stresses. A multiple tourniquet approach to intermittently obstruct venous return from the periphery has been devised, simulating the hydrostatic pressure effects of standing and thereby "triggering" compensatory cardiovascular reflexes. Following 6-hour periods of water immersion with tourniquet protection, the orthostatic tolerance of 5 subjects was determined and compared with that obtained following previous 6-hour immersion tests with no protection. In all subjects the tourniquet technique maintained normal or better than normal cardiovascular adaptability as measured by tilt-table testing.

30. Graveline, D. E.
Maintenance of cardiovascular adaptability during prolonged weightlessness. In MEDICAL AND BIOLOGICAL PROBLEMS OF SPACE FLIGHT: PROCEEDINGS OF A CONFERENCE HELD IN NASSAU, THE BAHAMAS, NOVEMBER 1961. G. H. Bourne., (ed). N. Y. Academic Press, 1963, pp. 115—122.

Brief description of a multiple tourniquet technique to maintain cardiovascular adaptability during prolonged zero-g exposure. The technique intermittently obstructs venous return from the periphery, simulating the hydrostatic pressure effects of standing, and thereby "triggering" compensatory cardiovascular reflexes. Following 6-hour periods of water immersion with tourniquet protection, the orthostatic tolerance of 5 subjects was determined and compared with that obtained following previous 6-hour immersion tests with no protection. In all subjects the tourniquet technique maintained normal or better than normal cardiovascular adaptability as measured by tilt-table testing.

31. Graveline, D. E. and B. Balke
PHYSIOLOGICAL EFFECTS OF HYPODYNAMICS INDUCED BY WATER IMMERSION,
USAF School of Aviation Medicine, Brooks AFB, Texas. SAM Rept. no. 60-88,
Sep 1960.

32. Graveline, D. E. and B. Balke
THE PHYSIOLOGIC EFFECTS OF HYPODYNAMICS INDUCED BY WATER IMMERSION.
School of Aviation Medicine, Brooks AFB, Texas. Research Rept. 60-88, Sep 1960.
AD 247163.

Body immersion in water was used to produce an experimental situation in which the normal weight sensation was altered and in which slow movements were effortless. The hypodynamic effects of such immersion on orthostatic tolerance, on cardiorespiratory adaptability to physical stress, and on other biologic and psychophysiologic parameters were studied on one human subject in experiments of 2 and 7 days duration, respectively. Pronounced functional deterioration resulted from the hypodynamic situation in both experiments; cardiovascular reflexes were severely disturbed and muscular tone was diminished. The extensive biochemical studies on blood and urine showed marked deviations from the normal. Psychomotor effectiveness, tested on a complex systems task, was impaired noticeably. The need for sleep appeared to be markedly reduced during the periods of water immersion.

This area of research is vital to the man-in-space program. Weightless or near-weightless conditions in space flight are expected to produce a similar hypodynamic effect on the organism as was caused by water immersion. Such loss of functional reserves may severely interfere with the astronaut's capability to adjust adequately to returning gravitational forces.

33. Graveline, D. E., B. Balke, et al
PSYCHOBIOLOGIC EFFECTS OF WATER-IMMERSION-INDUCED HYPODYNAMICS,
Aerospace Medicine 32(5): 387-400,
May 1961.

A weightless environment in which movement was effortless was produced by whole body immersion in water. One subject was immersed for seven days. The data collected during that time indicated that serious functional impairment results from prolonged exposure to hypodynamic conditions.

34. Graveline, D. E. and G. W. Barnard
PHYSIOLOGIC EFFECTS OF A HYPODYNAMIC ENVIRONMENT SHORT TERM STUDIES.
Aerospace Medicine 32(8): 726 – 736, Aug 1961.
See also (Wright Air Development Division, Wright-Patterson AFB, Ohio) WADD TR 61-257; AD-262 992.

By a technique involving complete immersion in water, a hypodynamic situation was produced in which normal weight sensations were altered and movement was relatively effortless. Four subjects were evaluated after 6, 12, and 24 hours of this environment. Tilt table, centrifuge, and heat chamber studies demonstrated significant cardiovascular deterioration even after the 6-hour runs, becoming more severe with the 12- and 24-hour experiments. Pertinent psychomotor evaluations, anthropometric measures, and urine and blood studies also were done. The results of this study indicate that the cardiovascular adaptation to a hypodynamic environment of this type occurs early and the deterioration from even a 6-hour exposure is apparent.

35. Graveline, D. E. and M. M. Jackson
DIURESIS ASSOCIATED WITH PROLONGED WATER IMMERSION. Report on Biophysics of Flight. Aerospace Medical Lab., Aeronautical Systems Div., Wright-Patterson Air Force Base, Ohio. ASD TR 61-651, Dec 1961. AD-273 201.

Utilizing complete water immersion, balanced respiration, and unrestricted activity, the diuretic response of five human subjects to 6-hour periods in this environment was studied. The results indicate that the low specific gravity diuresis which occurs in this situation is of the water-diuresis type, with decreased urinary concentrations of sodium, potassium, urea, and creatinine.

36. Graveline, D. E. and M. M. Jackson
DIURESIS ASSOCIATED WITH PROLONGED WATER IMMERSION. J. Appl. Physiol. 17(3): 519 – 524, May 1962.

Utilizing complete water immersion, compensated respiration, and unrestricted activity, the diuretic response of five human subject to 6-hour periods in this environment was studied. The results indicate that the low specific gravity diuresis which occurs in this situation has characteristics of both a water and an osmotic diuresis. Possible physiologic mechanisms are discussed.

37. Graveline, D. E., M. McCally and M. M. Jackson
Mechanisms of the water-immersion diuresis. IN
34th Annual meeting, Aerospace Medical Association,
1963. Aerospace Med. 34(3): 256, 1963. (Abstract)

Paper given at 34th Annual Meeting Aerospace Med. Assoc. 1963.

38. Graveline, D. E. and M. McCally
SLEEP AND ALTERED PROPRIOCEPTIVE INPUT
AS RELATED TO WEIGHTLESSNESS: WATER
IMMERSION STUDIES. Aerospace Medical Research
Labs., (6570th), Aerospace Medical Div., Biomedical
Lab., Wright-Patterson AFB, Ohio. AMRL-TDR-62-83.
AD 286022. (Abstracted in Aerospace Medicine, v. 34,
no. 1, p. 74, January 1963).

The "free-floating" condition of immersion is associated with substantial alterations in mechano-receptive feedback to the central nervous system in a manner similar to the free-floating condition of weightlessness. In this study electroencephalographic and electrooculographic recordings were made during sleep of completely immersed, neutrally buoyant subjects. Sleep records obtained while using both tether and clam-shell sleeping facilities were compared to each subject's normal bedrest sleep records. The results are presented, and their possible application to prolonged weightlessness is discussed.

39. Graybiel, A. and B. Clark
SYMPTOMS RESULTING FROM PROLONGED
IMMERSION IN WATER: THE PROBLEM OF
ZERO G ASTHENIA. (Naval School of Aviation
Medicine, Pensacola, Fla.) (Proj. MR005.15-2001.1.4),
25 July 1960; AD-244 932. (See also Aerospace Medicine
32(3): 181 – 196, Mar 1961).

In order to reduce the effects of G on the body, three subjects were floated in tanks of physiological saline solution for ten hours per day for two weeks while systematic attempts were made to eliminate any effects of sensory deprivation.

40. Graybiel, A. and B. Clark
SYMPTOMS RESULTING FROM PROLONGED IMMERSION IN WATER: THE PROBLEM OF ZERO G ASTHENIA. (US Naval School Aviat. Med. Res., Pensacola, Fla.) Jun 15, 1960. Rep. MRoo5.15-2001, (Subtask 1, Rep. 4: 1-27).

41. Hammer, Lois R.
AERONAUTICAL SYSTEMS DIVISION STUDIES IN WEIGHTLESSNESS: 1959 – 1960. Aerospace Medical Laboratory, Aeronautical Systems Division, W-P Air Force Base, Ohio. Dec 1961. (Proj. 7184; Task 71595). WADD TR 60-715. AD 273098.

Facilities and techniques used at Aeronautical Systems Division to study the effects of weightlessness are described; completed experiments and those started before January 1961 are discussed. Topics are grouped under two main headings: aerospace medical studies and aeromechanics studies. Specific problem areas and methods of experimentation are emphasized. Findings are briefly stated.

The Biomedical Laboratory Water Submersion Task is discussed in Section 11, Facilities and Methodology. Studies of the Psychophysiological Effects of Prolonged Weightlessness employing the water submersion tank are discussed in Section 111, Aerospace Medical Studies.

42. Hunt, Noel C., III
A FACTORIAL STUDY OF IMMERSION DIURESIS AND ITS INHIBITION BY POSITIVE PRESSURE. (USAF School of Aerospace Medicine, Brooks AFB, Texas.) Paper given at Aerosp. Med. Assoc. 36th Annual Meeting, April 1965, N. Y.

This study was sought to further define the nature of a water immersion diuresis and to attempt to counterbalance the negative pressure breathing (NPB) inherent to water immersion with properly applied positive pressure. In this manner, a simulated weightlessness environment is presented in which water pressure counterbalances the usual hydrostatic gradients of the vascular system, without the artefactual NPB element.

A panel of subjects has been submitted to a factorial analysis to compare urine volume and composition during routine activity, recumbency, and water immersion (semi-supine with headout). A continuous-flow respiratory system using weighted spirometers was evaluated for (a) absence of intrinsic diuretic stimuli at zero pressure, which have been noted even in low resistance respiratory equipment, and (b) ability to produce antidiuresis at positive pressures. These standards were attained. Measurements of the negative pressure imposed by head out immersion were made.

Current analysis includes four subjects, with an anticipated total of ten. The subjects were dehydrated and submitted to six hours of the various regimens, with urine collected hourly for volume and composition. Using the urine of routine activity as control, the volumes during recumbency and immersion increase 230 per cent and 354 per cent, respectively. Application of 15 cm H_2O respiratory pressure to immersed subjects reduced the volume to 254 per cent. Sodium values, presented as above were 204 per cent and 294 per cent, respectively, returning to 199 per cent during positive pressure, application. Comparison of recumbency and immersion urines reveals a qualitatively similar composition, the implication of which will be discussed. Absolute amounts of creatinine excretion revealed minimal differences between treatments, in contrast to previously reported findings; standard GFR studies are being initiated. Finally, comparison of immersed subjects with and without respiratory counterpressure will be presented.

43. Knight, L. A.

AN APPROACH TO THE PHYSIOLOGIC SIMULATION OF THE NULL-GRAVITY STATE.

J. Avia. Med. 29(4): 283 – 286, Apr 1958.

While studying the physiological effects of prolonged weightlessness the similarities between the condition of a body floating in space and that of a body floating in water were noted, and the conclusion was drawn that weightlessness is the absence of external forces acting on the body. It was assumed that a physiologic condition approaching that observed in the null-gravity state could be simulated by obscuring vision, immersing the subject in water to eliminate tactile and proprioceptive cues, and positioning him in the supine, head-down orientation. A preliminary experiment (three subjects acquainted with conditions of null-gravity) was conducted to investigate the matter of spatial orientation during immersion in water, and to establish values for the threshold of sensitivity of the otolith organ to change in position.

44. Lawton, Richard W.

THE PATHOPHYSIOLOGY OF DISUSE AND THE PROBLEM OF PROLONGED WEIGHTLESSNESS: A REVIEW. Report for Dec 1960 – Mar 1963. Jun 1963, 46p. General Electric Co., Philadelphia, Pa. (Proj. 7222, Task 722201). AMRL TDR63-3. AD-417 395.

The physiological implications of zero-G as encountered in space flight are discussed and the available research concerning the physiological effects of weightlessness is reviewed. The purpose of this review is to proceed from the present state of knowledge of normal human physiological systems, particularly as their structure and function are affected by gravity, to a consideration of the possible physiological consequences of prolonged human exposure to zero-G. Methods used to produce and to simulate zero-G are briefly reviewed. The data suggesting that prolonged weightlessness will be a deconditioning environment is presented. This data is considered for possible untoward effects of prolonged exposure to weightlessness, and for methods of prevention of undesired effects. The problem of artificial gravity by rotation of a space vehicle is briefly considered. Areas of needed future investigation are suggested.

45. Lawton, R. W.

Physiological considerations relevant to problem of prolonged weightlessness. ASTRONAUTICAL SCIENCES REVIEW 4(1):11 – 18, 31 – 38, Jan – Mar 1962.

Review of studies of inactivity and confinement to determine effects of immobilization and bed rest, and submersion in water; cardiovascular effects, bone demineralization; muscle atrophy; otolith functions; semicircular canal phenomena; slow rotation room and selection and training of astronauts.

46. Loftus, J. P. and L. R. Hammer

Weightlessness and Performance: A Review of the Literature, Aerospace Medical Laboratory, Wright-Patterson Air Force Base, Ohio, Jun 1961, ASD-TR-61-166.

The implications of weightlessness as encountered in space flight are discussed, and the known research dealing with the psychological and physiological effects of zero gravity is critically reviewed. Topics are grouped under the headings of orientation, psychomotor performance, and physiological functions, with a special section of

methods of research. The major problem area indicated is the effect of weightlessness on gravity oriented sensory mechanisms, particularly the vestibular apparatus, and consequently on both physiological functions and psychomotor performance. An extensive bibliography is included.

Immersion techniques are discussed in the section devoted to Methods of Research, pp. 5–6, and a review of immersion studies reported in the literature published prior to April 1961 is presented in the section devoted to Physiological Functions, pp. 21–22.

47. McCally, Michael
Plasma volume response to water immersion: Implications for space flight. AEROSPACE MEDICINE 35(2): 130 – 132, 1964

Change in plasma volume of 5 subjects was measured during 6 hours of complete water immersion and during 6 hours of office activity control by hemoglobin and hematocrit dilution and with radio-iodinated serum albumin (RISA) techniques. The mean plasma volume increased 9% during the first 25 minutes of immersion and then decreased over the next 4 to 6 hours to approximately 11% less than the zero time value. The repeated injection and sampling of RISA is not a suitable technique for the measurement of acute changes in plasma volume. The mechanisms of the water immersion diuresis and post-immersion orthostatic intolerance are discussed and inferences made to human exposure to weightlessness.

48. McCally, Michael and Jack Goldman
FREE FATTY ACID RESPONSE TO TILTING FOLLOWING IMMERSION. Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio. Paper given at Aerosp. Med. Assoc. 36th Annual Meeting, April 1965, N. Y.

Orthostatic intolerance is seen in human subjects following prolonged bed rest and water immersion. Serum free fatty acids are released by noradrenaline and rise rapidly during the normal response to passive vertical tilt. Blood pressure, heart rate, plasma glucose and free fatty acid responses to a six degree vertical tilt for thirty minutes were studied in six subjects following six hours of complete water immersion, six hours of heat exposure simulating the thermal characteristics of the immersion and six hours of office activity control. Heart rate response to tilt was least after heat, greatest after immersion and significantly different in both cases from that following office control ($P<0.01$ paired samples). During tilt after heat and office control, free fatty acids rose normally. After immersion the free fatty acids fell 20 per cent ($p<0.01$) and then rose slowly toward control levels. Plasma glucose levels did not change significantly in response to any of the tilts. The impaired fatty acide response to tilt after immersion supports the hypothesis that the

known diminished urinary excretion of noradrenaline during water immersion reflects decreased sympathetic vasomotor activity in turn contributes to the orthostatic intolerance. The possible relationships of disuse and inactivity to the metabolism of noradrenaline are discussed.

49. McCally, Michael, Jack K. Goldman, and George W. Barnard
Sympathoadrenal response to water-immersion hypodynamics. In: 34TH ANNUAL MEETING, AEROSPACE MEDICAL ASSOCIATION, 1963. Aerospace Med. 34(3): 262, 1963.

50. McCally, Michael and Duane E. Graveline
Urinary catecholamine response to water immersion. U. S. Air Force Tech. Doc. Rept. AMRL-TDR-63-20. 1 – 10, 1963. AD407 741.

The urinary excretion of adrenaline and noradrenaline was measured by bioassay for 16 normal human subjects during 6 hours of complete water immersion. The excretion of adrenaline was moderately increased, possibly related to the anxiety associated with the immersion. The excretion of noradrenaline was significantly ($p<0.01$) reduced during immersion. Six subjects were studied during passive vertical tilt following immersion. Orthostatic intolerance was demonstrated and the increase in pulse rate and decrease in pulse pressure were significantly different from the control tilt. The probable mechanisms of the reduced noradrenaline excretion during immersion and its relation to the postimmersion impairment of orthostatic tolerance are discussed.

51. McCally, M. and D. E. Graveline
Urinary adrenaline and noradrenaline response to water immersion. FED. PROC. 22(2Pt. 1): 508, 1963. Paper given at 47th Annual meeting of the Federation of American Societies for Experimental Biology, 1963.

52. McKenzie, R. E., B. Hartman and D. E. Graveline
An exploratory study of sleep characteristics in a hypodynamic environment. School of Aerospace Medicine, Brooks AFB, Texas. Rept. SAM 60-68, Oct 1960.

Sleep characteristics were monitored and evaluated by eeg technics during an exploratory study of biologic hypodynamics produced by body immersion, three kinds of changes in sleep characteristics were seen: (a) a reduction in the total amount; (b) a constriction in the range of sleep states; and (c) a progressive improvement in the stability of sleep states. The hypothesis is advanced that the biologic function of sleep may be to provide a recovery period from the neuromuscular debt acquired from the effects of counteracting the forces of gravity. This has several implications for space travel in the weightless state.

53. Meineri, G.
THE EFFECTS OF SUBGRAVITY AND THE METHODS FOR REPRODUCING IT ON THE GROUND AND IN FLIGHT. Rivista di medicina aeronautica e spaziale (Roma), 26 (1): 80–98. Jan – Mar 1963. (In Italian, English summary (p. 94)).

A review of the literature is presented which deals with experiments on the physiological effects of subgravity. The chief methods used to simulate subgravity conditions are described and a distinction is made between ground methods (immersion of all or part of the body in water, high acceleration exposure), and the more cumbersome methods through which actual or complete subgravity can be attained (parabolic flight, suborbital and orbital launching). The accomplishments are reported of the Center of Studies and Researches in Aerospace Medicine, Rome, which uses a subgravity tower for experiments. This tower is of great value in obtaining data on the physiological effects of short-term subgravity similar to that encountered in space flight, such as transition between the active and passive stage of flight, the effects on psychomotor behavior, the role played by the labyrinth and its components, etc. The possible extension of these methods into worldwide space research projects is discussed.

54. Reeves, E., E. L. Beckman, and R. E. DeForest
Physiological effects resulting from different types of fluid replacement during water immersion. Aerospace Med. 34(3):234, 1963. (Abstract). Paper given at 34th Annual Meeting Aerospace Med. Assoc. 1963.

55. Rubiowsky, John
Man in a tub. SPACE WORLD, 1:14–15, Jul 1960.

Discussion of Capt. Graveline's seven days in 400 gallons of warm water.

56. Stone, Ralph W. Jr., and William Letko
SOME OBSERVATIONS DURING WEIGHTLESSNESS SIMULATION WITH SUBJECT IMMERSED IN A ROTATING WATER TANK. National Aeronautics and Space Administration. Langley Research Center, Langley Station, Va. Sep 1964, 22p. (NASA-TN-D-2195). N64-30094.

An investigation was made with a rotating water tank to determine the feasibility of the water-immersion technique for weightlessness simulation, including an attempted elimination of the otolith cues by rotation. Because of the early orbital flights the experiments were not continued and the technique was not fully evaluated; however, the experiences encountered are believed to be of general interest and of some possible physiological consequence.

57. Vallbona, C. et al
THE EFFECT OF BEDREST ON VARIOUS PARAMETERS ON PHYSIOLOGICAL FUNCTION: PART I. Review of the literature on the physiological effects of immobilization. NASA CR 171, Mar 1965.

Presents a discussion of the studies that have been done on water immersion.

58. Vanyushina, Yu. V.
FUNCTIONAL CHANGES IN THE CARDIOVASCULAR SYSTEM AFTER EXPOSURE TO HYPODYNAMIA. National Aeronautics and Space Administration, Washington, D. C. In its Aviation and Space Med. Dec 1964, pp. 76–78. N65-13653.

An attempt was made to determine how the cardiovascular reflexes that resist gravity might change in human beings required to remain a long time in circumstances that limit reflex impulses from the muscles and cardiovascular system. Experiments

involving subjects immobilized for 5.5 to 10.5 days in a special armchair in a position of maximum muscular relaxation and involving subjects who remained suspended in a tank of water for 5.5 to 11.5 days were performed. It was found that in human beings remaining for a long period of time under conditions of limited mobility, the adaptive reactions of the cardiovascular system to the force of gravity decrease. The weakening of the mechanisms was magnifested during orthostatic testing, by a sharp acceleration of the pulse, a drop in systolic and pulse pressure, and slight cerebral anemia.

59. Vogt, Fred B.
EFFECT OF EXTREMITY CUFF-TOURNIQUETS ON TILT TABLE TOLERANCE AFTER WATER IMMERSION. Aerospace Medicine, 36:442–447, May 1965 (NASA-sponsored research).

Experimental investigation of the tilt-table intolerance of four healthy adult young males in two water-immersion tests of 6-hours duration, in an effort to reproduce a previous study reporting a protective effect from cuff-tourniquets applied to the extremities during immersion. Body weight, fluid intake, urine output, and leg circumference measurements were made and recorded. After the first period of six hours of water immersion, three of the four subjects experienced syncope during a tilt-table test. Compared to pre-immersion tilt tests, all subjects experienced marked changes in heart rate or blood pressure during tilting after immersion. A significant diuresis was not noted. During the second period of immersion, cuff-tourniquets were applied to the four extremities and inflated to a pressure of 60 mm Hg, with a cycle of 1 min on, 1 min off. Some degree of protection against tilt-table intolerance after immersion was provided in the test; none of the three subjects experienced syncope or showed the marked blood pressure changes they had shown on the previous immersion test without cuffs.

60. Vogt, Fred B. and Philip C. Johnson
STUDY OF EFFECT OF WATER IMMERSION ON HEALTHY ADULT MALE SUBJECTS – PLASMA VOLUME AND FLUID-ELECTROLYTE CHANGES. Aerospace Medicine, 36:447–451, May 1965. (NASA-sponsored research).

Experimental investigation of four healthy adult males during two water-immersion experiments of 6-hours duration. During the second experiment, cuff-tourniquets were applied to all four extremities of each subject to test the effect in preventing or lessening the cardiovascular deconditioning associated with water immersion. The use of the cuff-tourniquets was found to be partially effective. Repeated plasma volume, hemoglobin, hematocrit and serum sodium, potassium, osmolarity, and

protein determinations were performed and are reported. Measurements of fluid intake, urine output, and body weight are reported. An increased transfer rate of intravascular compartment is suggested as one of the possible factors responsible for the symptoms observed during tilt-table tests after water immersion.

61. Warren, Bruce H.
A COMPARISON OF PHYSIOLOGICAL CHANGES OCCURRING DURING WATER IMMERSION AND BED REST. Paper: 34th Annual Meeting of the Aerospace Medical Association, Statler-Hilton Hotel, Los Angeles, Calif., Apr 28 – May 2, 1963.

Human water immersion experiments have been performed by several investigators under the assumption that the resulting "hypodynamic" environment simulates certain conditions of weightlessness. Bed rest has also been used as a method for studying the hypodynamic state. In the present investigation a controlled comparison of these techniques was made. Twelve healthy male volunteers took part in these experiments. Each subject was studied during two 6-hour water immersion periods and one 6-hour bed rest period. Physical and psychological variables were kept as constant as possible. Electrocardiograms were traced continuously and blood pressures were recorded automatically. Blood and urine samples were collected for physical and chemical determinations. A tilt table was used to produce gravitational stress for measuring cardiovascular responses before and after each hypodynamic period. An analysis of the data revealed that the direction of change of a physiological parameter during water immersion coincided with the direction of change of the same parameter during bed rest. The biological relationship of the above hypodynamic factors to weightlessness can only be hypothesized. Further evaluation of physiological changes occurring during water immersion and bed rest appear warranted, however, before either is accepted as a better tool than the other for studying the hypodynamic state in man. In over thirty hypodynamic periods above, no sifnificant differences were noted in the physiological parameters measured during water immersion and bed rest which could not be attributed to factors other than an increased hypodynamic state during water immersion.

62. WATER IMMERSION STUDIES: A REPORT BIBLIOGRAPHY.
Defense Documentation Center, Cameron Station, Alexandria, Va. Report No. ARB-035224, Jun 1965.

A report bibliography requested from Defense Documentation Center. It contains 25 references pertaining to the use of water immersion studies to simulate weightlessness.

63. Wunder, Charles C.
A SURVEY OF CHRONIC WEIGHTLESSNESS SIMULATION IN BIOLOGICAL RESEARCH.
Virginia Univ., Charlottesville. 1964, 122p.
(Contract AF18 600 2057). AD 607052.
Prepared in cooperation with Iowa State Univ., Iowa City, the National Institutes of Health, and the American Cancer Society.

The central emphasis of the survey concerns the status of research involving various methods of effecting chronic weightlessness for organisms. Three general types of approach are considered: (1) accelerations that oppose the Earth's gravity, (2) indirect reduction of gravitational effects, and (3) indirect information from increases of gravitational load. After initiation of this survey, the Air Force requested particular consideration of immobilization as one type of approach to the problems of weightlessness simulation. Immobilization (by means of casts, splints, tenotomy, and denervation) is considered as one aspect of the second category listed above. Other aspects of that category are bed rest, support by frictionless devices, buoyant support (during water immersion), and tumbling.

PART II: HUMAN ENGINEERING STUDIES

64. Beckman, E. L.
A REVIEW OF CURRENT CONCEPTS AND PRACTICES USED TO CONTROL BODY HEAT LOSS DURING WATER IMMERSION. AD 614241. Naval Medical Research Inst., Bethesda, Md. 1964, 33p. Research rept. no. MR-005.13-4001.06, R-3.

Presented to the Aerospace Medical Panel General Assembly of Advisory Group for Aeronautical Research and Development (14th), held at Lisbon, Portugal, 12 Sep 64. Available copy will not permit fully legible reproduction. Reproduction will be made if requested by users of DDC. Copy is available for public sale.

The problem of providing adequate clothing for personnel who either during normal operations or accidentally are immersed in cold water has continued to challenge clothing manufacturers. In the past decade the development of foamed plastics and other clothing materials has offered new possibilities. Likewise advances in energy conversion and storage systems offer new solutions to this critical operational problem. The basic physical and physiological concepts which relate to the problem of limiting thermal loss from the immersed human will be reviewed. Newer technical developments in insulative clothing and supplemental heating systems will be discussed with relation to these basic concepts.

65. Chaffee, John W., Albert F. Emanuel, and James E. Mabry.
NEUTRAL BUOYANCY AS A MEANS OF SIMULATING 0-G EFFECTS ON HUMAN PERFORMANCE. The Boeing Company, Aero-Space Division, Seattle, Washington. Paper given at Aerosp. Med. Assoc. 36th Annual Meeting, Apr 1965, N. Y.

By ballasting space systems operators to neutrally buoyant in water, it is possible to simulate many of the effects upon man's gross motor behavior in the zero gravity environment. To the extent that these are analogous with those to be encountered when weightless in space, the systems designer is provided with important pre-launch information descriptive of human capabilities and requirements in systems operation, maintenance and assembly.

(see also references 10, 46, 62, 94, 95)

This paper describes the experimental techniques, facility requirements, and experimental results of an exploratory program directed toward acquiring an operational description of simulated zero-gravity effects on the operation performance. Quantitative data and films will be presented.

66. Chambers, R. M., D. A. Morway, et al
THE EFFECTS OF WATER IMMERSION ON PERFORMANCE PROFICIENCY. Aviation Medical Acceleration Lab., Naval Air Development Center, Johnsville, Pa. 22 Aug 1961. Rept. no. NADC-MA-6133. AD-267 665.

In an attempt to study a wide range of human performance abilities associated with weightlessness and the transition from weightlessness to a high G reentry environment, the technique of water immersion and centrifugation was used to simulate these conditions. Six male subjects were immersed in water to the neck level for a 12-hour period and one subject for a 23-hour period. Eight selected performance tasks were administered: (1) before immersion, (2) during immersion, (3) after immersion and centrifugation so that gross motor and perceptual behavior could be sampled. It was found that behavior was not apparently affected by prolonged water immersion followed by reentry type accelerations.

67. Chamber, R. M., D. A. Morway, et al
CHANGES IN PERFORMANCE PROFICIENCY UNDER CONDITIONS SIMULATED BY WATER IMMERSION AND CENTRIFUGATION. (Paper, 32nd Annual Meeting of the Aerospace Medical Assoc., Palmer House, Chicago, Illinois, Apr 24 – 27, 1961).

68. Clark, C. C. and R. F. Gray
A DISCUSSION OF RESTRAINT AND PROTECTION OF THE HUMAN EXPERIENCING THE SMOOTH AND OSCILLATING ACCELERATIONS OF PROPOSED SPACE VEHICLES. U. S. Naval Air Development Center, Aviation Medical Acceleration Lab., Johnsville, Pa. Rept. No. NADC-MA-5914, Dec 28, 1959. (Project TED ADC AE 1412).

The thesis of this paper is that it is not the forces generated by acceleration or deceleration (at least to somewhat beyond 30G) which damage man, but rather the body distortions which can result from an unbalanced action of these forces. By proper "packaging" of the human tolerance will depend on the consequences of local tissue compression or extension rather than on the consequences of gross tissue and organ displacements and distortions. The acceleration time histories to accelerate to and decelerate from the velocities suitable for space travel are presented with emphasis that presently attained velocities are only a beginning. Minimum travel time involves acceleration for half the trip and deceleration for the other half. Techniques of centrifuge simulation of these accelerations are presented. The dependence on vehicle configuration of vehicle decelerations be reentry into an atmosphere is noted. Vehicle oscillations induced by motor and by lift misalignments are described. The ability of the human to make body motions while under acceleration determines the minimum necessary restraint for the head and limbs. To minimize involuntary pilot control inputs, a simultaneous designing of restraints and controls is necessary. A moulded body form "contour couch" provides a broadened support and reduces body distortion. In such a couch, a man has reached +25 G_x (chest-to-back) as the peak acceleration of a versine waveform with a 40-second period. Tight bandaging of the body and particularly training in techniques of complete body straining are important aspects of these experiments.

69. Diefenbach, W. S.
THE ABILITY OF SUBMERGED SUBJECTS TO SENSE THE GRAVITATION VERTICAL. A PILOT STUDY. Cornell Aeronautical Lab. Inc., Buffalo, N. Y. Jan 1961, 39p. Ad-445 369.

The ability of human subjects to perceive the vertical when submerged in a buoying fluid and subjected to varying amounts of body tilt was studied in a series of pilot experiments. Experimental equipment employed attempted to minimize positional cues other than those arising from the vestibular apparatus and visceral sources. Gross errors in perception of the vertical were made by all subjects. These errors

were repeatable within subjects, and had a high linear correlation with the amount of body tilt. In addition, evidence was found that precision in positioning an unseen control may vary with body tilt. Possible simulation of weightlessness and implications for design of space controls are briefly discussed and further research studies are suggested.

70. Ferguson, John C. and Randall M. Chambers
PSYCHOLOGICAL ASPECTS OF WATER IMMERSION STUDIES Report No. 7. Naval Air Development Center, Johnsville, Pa., Aviation Medical Acceleration Lab. 30 Dec 1963, 28p. (NADC-MA-6328; AD-429523), N64-15755.

The purpose of this paper was to review the recent water immersion literature, placing special emphasis on the psychological aspects of these studies. The adequacy of water immersion as a technique for simulating weightlessness was discussed, and water immersion facilities and procedures were described. The areas of perceptual and motor performance, boredom and fatigue, sleep, orientation, and personality and emotional aspects of water immersion were selected as being of special psychological interest.

71. Hanna, Thomas D.
Psychomotor performance during total body water immersion for massed and sp[illegible]d learning on a complex task. AEROSPACE MED. 34(3):256, 1963, (Abstract). Paper given at 34th Annual Meeting Aerospace Med. Assoc., 1963.

72. Hartman, B., R. E. McKenzie, and D. E. Graveline.
AN EXPLORATORY STUDY OF CHANGES IN PROFICIENCY IN A HYPODYNAMIC ENVIRONMENT. School of Aviation Medicine, Brooks Air Force Base, Texas. Report No. 60-72, Jul 1960. AD 244 121.

Simulated weightlessness for a prolonged period was produced by the body immersion technic. Changes in psychomotor efficiency was assessed during immersion and after

return to the normal environment of 1 G. Systematic changes in a relatively simple task were obtained during immersion. Gross disruptions in psychomotor behavior on return to the normal environment were observed. Accompanying this were increased response times on three different kinds of tasks in a systems operator simulator. These results suggest that the functional capabilities of a man, while adequate during prolonged weightlessness, will be seriously impaired during the reentry phase of space flight.

73. Hauty, George
(Federal Aviation Agency, Aeromedical Service, Civil Aeromedical Research Institute, Oklahoma City, Okla.).
PSYCHOPHYSIOLOGICAL PROBLEMS IN SPACE FLIGHT. IN: BIOASTRONAUTICS. New York, Macmillan Co. 1964, pp. 196–224.

Review and discussion of the problems of weightlessness, vigilance, and sensory deprivation. Prolonged simulated weightlessness was studied by immersing a subject (clad in a rubber suit) in a tank of water up to his neck for 7 days, removing him for only brief periods once each day. During immersion, operator performance exhibited a slight progressive decline which the author attributes to a decline in motivation. Little physiological impairment was noted although the nature and duration of the sleep states were said to have changed markedly. In the studies of vigilance and sensory deprivation, subjects were assigned the problem of flying a simulated space mission. The investigation of vigilance required the subject(s) to perform without interruption a complex series of tasks over a 30-hr period. Objective and subjective reactions to changes in the work load were monitored. In both the vigilance and the sensory-deprivation experiments the comments of the test subjects were recorded.

74. King, B. G., C. T. Patch, and P. G. Shinkman
Weightlessness – Training Requirements and Solutions. U. S. Naval Training Device Center, Port Washington, New York, 3 Mar 1961, NAVTRADEVCEN 560-1.

Physical principles and biological mechanisms relevant to human performance under conditions of weightlessness have been explained in order that the trainee can develop an appreciation of how the unaccustomed environment will affect his behavior. Special emphasis has been given to (a) changes of man's center of mass as various parts of the body are moved with respect to each other, and the significance of CM for body movement, (b) the mechanisms of postural reflexes, including experimental observations of response of pigeons to postural disorientation by tilting during weightlessness,

and (c) anticipated changes in the sensory input spectrum and implications of such changes. Models have been proposed as visual aids in providing for cognitive learning aspects of training. The different effects of weightlessness on motor-perceptual and perceptual factors have been identified and solutions proposed for separately training each of these effects.

...Normally a body in contact with the earth is supported against gravity at localized sites and the body is provided with sensory mechanisms for referring sensations to the point of contact of the supporting force. This aspect of weightlessness can be simulated in an "earth trainer" by providing trainees with suitably-designed clothing and submerging them in a water tank... In this situation the supporting force of the body is distributed over a large surface area and the body would feel much as it would in weightlessness... The stimuli that are associated with maintenance of body posture that are experienced by the utricle and the viceral afferent nerve endings will be identical with those experienced on a rigid support, and the trainee will probably be able to orient himself with respect to gravity even in the absense of visual and tactile cues. The disadvantages of such a device (water tank) will be the greater density of the medium and the pressure gradient with respect to depth.

75. LOG OF THE AQUANAUTS
Naval Research Reviews, pp. 16–17, 19– 25,
Sep 1964.

A discussion of the operational phase of Project Sealab 1. This is a recorded version of what transpired during 11 days of working both inside and outside of the 40 foot long chamber maintained at a pressure equal to that of the surrounding water and while breathing from an atmosphere consisting mostly of helium.

76. MAN IN SPINNING TANK OF WATER WILL TEST
EFFECTS OF WEIGHTLESSNESS IN SPACE.
Army Navy Air Force Journal, 97:21, 23 Apr 1960.

77. Morway, Donald A., Richard G. Lathrop, et al
THE EFFECTS OF PROLONGED WATER IMMERSION ON THE ABILITY OF HUMAN SUBJECTS TO MAKE POSITION AND FORCE ESTIMATIONS. Aviation Medical Acceleration, Lab., Naval Air Development Center, Johnsville, Pa. 24 Jul 1963, 21p. NADC MA6115;5. AD-414 349.

Twelve subjects using underwater breathing apparatus were immersed in water for 18 hours. Each subject's responses to two general psychomotor tasks: (1) the ability

to reach and position the arm and hand accurately and (2) the ability to estimate a prelearned level of force, were measured before, during and after water immersion. Analysis of variance performed upon the target aiming task showed no significant difference in the horizontal aiming component. However, a highly significant (p less than .01) bias upwards was observed in the vertical aiming component. Comparisons between trial means using the Duncan q' test indicates that the bias upwards declined as a function of immersion time. An analysis of variance performed upon the force estimation data showed a significant interaction between trials within blocks and test conditions. Duncan's q' Test Ordered Means Comparison revealed no significant difference between the pre- and post-immersion force estimations. The mean estimation obtained during immersion was significantly different (p less than .01) from the pre and post trials. The force data showed no tendency to adapt as a function of time immersed.

77A. Nordby, F. J.
Preparation for Lunar Environment with Means of Varying Gravitational Environment. SAE – Paper 758A for meeting Sep 23–27, 1963, 3p.

Paper describes method which may be used to investigate, test, or evaluate functions, operations, or performance of man/machine systems under various (or varying) gravitational environments; method could be employed to acquire information on time required to accomplish functions, developing methods of performance, verification of design, personnel selection, etc; method is simmersion technique based on controlled variations of density (specific gravity) of fluid mass. It was developed as part of a research experiment – to supplement existing techniques.

78. Pierce, B F. and E. L. Casco
Crew Transfer in Zero G as Simulated by Water Immersion. General Dynamics/Astronautics, San Diego, Calif., 15 Apr 1964, GDA-ERR-AN-502.

...The essential characteristic of man that makes water immersion a feasible method of weightless simulation for analyzing this (the relationship of man to equipment)... is that the specific gravity of the human body is equal to about one. Having approximately neutral buoyancy, the subjects representing the crew can assume positions and movements relative to the mockup which are similar to those that would occur in weightlessness, but which would be unattainable under one-G conditions.

The major limitation of this technique results from the fact that water offers considerable resistance to movement, and the resultant restriction to body mobility (as well as the possibility of using this resistance for self propulsion) must be taken into consideration. Nevertheless, water immersion provides the best simulation of weightlessness for periods of unlimited duration and with equipment of unlimited size.

79. Santa Maria, Louis J., Morris J. Damato, and Meredith H. Radliff
A physiological evaluation of the divers' wet suit in simulated flight and emergency environments.
AEROSP. MED. 35(2): 144–147, 1964.

The results of the physiological responses concerning skin and rectal temperatures of subjects wearing the divers' wet suit during exposure to different levels of environmental conditions are presented. Exposures were of 4 generic types: 1) two-minute immersion followed by life raft occupancy, 2) a constant immersion state, 3) dry-cold exposure, and 4) exposure to ambient conditions of moderate temperature. Results indicate that usage under most acceptable laboratory conditions only may constitute basis for favorable comparison with current exposure suit assemblies in regard to body temperatures and tolerance times. Reduction of water leakage and the introduction of ventilating capabilities might enhance its acceptability as a constant-wear protective assembly for the fixed-wing pilot and aircrewman.

80. SEALAB 1
Naval Research Reviews, pp. 5–8, Jul 1964.

Sealab 1 is sponsored by the Office of Naval Research in collaboration with the Bureau of Ships and the Naval Medical Research Laboratory, New London, Conn. The Sealab capsule was designed and constructed at the Navy Mine Defense Laboratory, Panama City, Fla.

The project was undertaken to help determine the extent to which man can adjust to the undersea environment and carry out useful assignments there.

81. Shurley, J. T.
PROFOUND EXPERIMENTAL SENSORY ISOLATION. Am. J. Psychiat. 117(6):539–545, 1960.

This is a description of the sensory deprivation experiments conducted at Oklahoma City Veterans Administration Hospital. In order to simulate weightlessness, the subject was placed in a large tank filled with water slowly flowing at a constant temperature. The rest of the system consisted of automatic controls and continuous tape recorders. The subjects were volunteers who had been pre-selected on the basis of capacity for memory, ability to communicate freely, and self-observation. Light, sound, vibration, odor, and taste inputs were highly restricted. The chronological report is based on tape recordings by a subject in isolation for 4-1/2 hours. The water immersion test was not perceived as unpleasant. The subjects feeling states varied during post-exposure.

82. A SURVEY OF CHRONIC WEIGHTLESSNESS SIMULATION IN BIOLOGICAL RESEARCH. Virginia U., Charlottesville. (HQARSC-TDR-64-1; AD-607052) N65-13216. (Contract AF 18 (600)-2057). 1964, 114p.

The experimental simulation of weightlessness by prolonged, quiet bed rest, by water flotation, and by body and/or limb immobilization is evaluated. The value of the simulation of a low-gravity environment by immobilization was found questionable because it produces the type of low activity characterized by reduced external motion, whereas a true weightlessness environment would not necessarily prevent external motion and might even permit greater amounts of such motions. It was found that studies of immobilization can be related to the restrictions that are imposed by the size of the existing space capsules, but should not be used to predict the effect of true weightlessness.

83. Weltman, Gershon, Raymond A. Christianson and Glen H. Egstrom A DIVER RESTRAINT DEVICE FOR UNDERWATER EXPERIMENTATION. Biotechnology Lab., Univ. of California, Los Angeles. Rept. nos. TN-30; 65-5, Feb. 1965, 6p. AD 463097.

There is currently a great deal of interest on many fronts concerning man's inhabitation of the sea. If this interest is a valid indication of future effort, as it seems to be, one may expect a significant increase in the number of experimental studies dealing with human work and task performance underwater. It seems reasonable to assume that the goals of these new studies will match the goals of previous investigations in other work environments. That is, there will be a similar emphasis on the psychophysiological effects of environmental variations, and on the ways in which equipment and workplace design influence performance level. For the underwater studies to be of equal practical value, however, they will also have to match the care and control of previous experimentation. This means that in many instances, because of the novel aspects of operating underwater, investigators will have to evolve, perfect, and communicate modified techniques for handling subjects, establishing work tasks, acquiring data, and so forth. Some brief remarks on the design and use of a diver restraint device applicable to several types of underwater study are presented.

84. Whiteside, T. C. D.
HAND-EYE COORDINATION IN WEIGHTLESSNESS.
Aerospace Medicine 32(8):719–725, Aug 1961.

To study hand-eye coordination under conditions that would eliminate the variable of visual monitoring of performance yet with eye movement controlled, Ss were required to point at graph paper situated some 20 to 25 inches from his chest at chest level. A thimble with a point was worn on the index finger so that accurate measurements could be made. A mirror was located in such a manner that the S saw a target situated to one side but could not see his hand and arm. The aiming task was performed under normal conditions, under simulation of subgravity (immersion in water up to neck), under zero g in an aircraft flying the well-known parabola, and under acceleration (2g) on the centrifuge. Practical implications of the findings were indicated.

85. Wolf, R. L.
The Use of Full Pressure Suits for Underwater Studies to Simulate Weightlessness. General Dynamics/Astronautics, San Diego, Calif., 1 Apr 1964, CDA-ERR-AM-495.

For evaluating some of the effects of a weightless environment, the approximately neutral buoyancy of the human body in water provides a suitable simulation. One of the most difficult problems in the use of full pressure garments in underwater testing is their positive buoyancy when inflated to normal pressures with air. For proper simulation it is necessary to have the underwater characteristics of the full pressure suit similar to those encountered in outer space. Any weights used to gain neutral buoyancy will add mass to particular points, making it difficult to control the center of gravity and to make normal body movements. For this test the technique of pressurizing the suit with water, although not of the most desirable quality, did provide a satisfactory means for partial simulation and gave valuable information for modification necessary for future tests.

86. Wright, N. Pelham (Ed.)
PROCEEDINGS FIFTH ANNUAL CONVENTION OF THE UNDERWATER SOCIETY OF AMERICA held in Mexico City, Jun 17–21, 1964. Published by C.E.D.A.M., Carlos B. Zetina 20, Mexico City 18, Mexico.

The purpose of this Congress was to discuss the latest developments in every branch of underwater activity. Section 11 of the proceedings is on Manned Undersea Stations.

87. Yuganov, Ye. M., P. C. Isakov, et al
MOTOR ACTIVITY OF INTACT ANIMALS
UNDER CONDITIONS OF ARTIFICAL GRAVITY.
(Akademiya nauk SSSR. Isvestiya., Seriya Biologicheskaya, no. 3, 455–460), 1962.

The minimal effective value of artificial gravity necessary to maintain the body posture and coordination of movements of mice and rats under conditions of weightlessness as in the parabolic flight of an aeroplane was determined. Artificial gravity was created in a small size contrifuge which produced radial accelerations varying from 0.05 to 1.0 g. Accelerations of 0.28 to 0.3 g were sufficient for prophylaxis of the unfavorable effect of weightlessness upon the motor reactions of the animals.

PART III: EQUIPMENT REQUIREMENTS FOR WEIGHTLESSNESS

88. Gerathewohl, S. J.
ZERO-G DEVICES AND WEIGHTLESSNESS SIMULATORS. National Academy of Sciences, National Research Council, Washington, D. C. Publication No. 781, 1961.

This report concerns the devices, methods, and techniques which have been used for the investigation of the effects of zero-G and weightlessness by many investigators. The report is not a scientific treatise of the problem of weightlessness and the effect of sub- and zero-gravity upon the organism, but rather a description of research equipment techniques.

Concerns the devices, methods, and techniques, which have been used for the investigation of the effects of zero-G and weightlessness by many investigators. Part I deals with devices which can be used for producing sub- and zero-gravity, viz., vertical-motion devices, aircraft, and ballistic missiles. A simple-mathematical treatment of the physical parameters involved in sub- and zero-G conditions precedes the discussion of each of these three methods. In Part II, instruments and techniques for the simulation of weightlessness are described. The objective of this survey is to assure maximum usefulness of such devices and optimum cooperation between agencies and to guarantee that new requirements of the future be incorporated in research proposals on bioastronautics.

89. Goodman, M. W.
CARBON DIOXIDE ABSORPTION SYSTEMS FOR SCUBA. 1. QUANTITATIVE CONSIDERATIONS OF DESIGN AND PERFORMANCE OF CYLINDRICAL CANISTERS. Navy Experimental Diving Unit, Washington, D. C. Interim rept., Research rept. RR-3-64. (Proj. S F011 06, 03, Task 3380). AD-615 771.
Available copy will not permit fully legible reproduction. Reproduction will be made if requested by users of DDC. Copy is available for public sale.

Cylindrical SCUBA canisters, packed with granular Baralyme, were tested with a mechanical respirator. Breathing resistance was observed to vary linearly and in

(see alo references 11, 16, 24, 41, 64, 65, 78, 79, 83, 85, 86)

direct proportion to the length-diameter ratio when airflow was of less than critical or pre-critical magnitude. Duration of useful canister life (end-point at 0.5% CO_2) was determined to be a function of canister size, i.e., volume and quantity of absorbent. Efficiency, however, correlates closely with the packed granular column length of iso-diamter, adequate-size canisters. Dimensions of low-flow-impedance, minimal-capacity canisters are governed by the absorptive wave-reactive-zone volume and the empirically-stipulated diameter. Methods for determining size, capacity and dimensional ratios of low resistance, efficient, duration-specific canisters are considered, together with the gas flow and composition parameters, the specific environmental hazards facing closed-circuit oxygen swimmers, and related factors of significance in these respects.

90. Gray, R. F. and M. G. Webb
HIGH G PROTECTION. Aviation Medical Acceleration Lab., Naval Air Development Center, Johnsville, Pa. 12 Feb 1960, 18p. (Proj. TED no. ADC AE 1411; rept. no. NADC-MA-5910). (Task MR005.12-0007.2. rept. no. 7). AD-235 338.

The advantages, problems, and limits of older types of G protective systems are discussed in this report. Theories are presented for methods of using liquid or form-fitting external supports for the body along with respiratory pressurization to counteract the distorting forces. Actual devices which were worked out to apply these theories are shown. These devices include: (a) the Mayo Tank first used in 1942 to test G protection by submersion in water. This has been slightly modified to bring about a substantial increase in G protection, (b) The G-Capsules and associated equipment, which most thoroughly of all devices so far built, is an application of these new theories of body support, and (c) the Moulded Couch built by the National Aeronautics and Space Administration according to some of these ideas and incorporating several other devices or procedures such as partial supination to avoid chest pain. Through the use of these various devices during the past year, several new records of tolerance to centrifugal acceleration have been established, indications have been gained for improvements on these devices, and it is expected that higher levels of G tolerance will be attained.

91. Haber, F. and H. Haber
POSSIBLE METHODS OF PRODUCING THE GRAVITY-FREE STATE FOR MEDICAL RESEARCH. USAF School of Aviation Medicine. Randolph AFB, Texas. 1951.

92. Levine, Raphael B.
(Lockheed-Georgia Co., Marietta, Ga.)
A Device for Simulating Weightlessness.
IN Medical and Biological Problems of
Space Flight, pp. 85–113. Proceedings of
a Conference held in Nassau, the Bahamas, Nov
1961. Ed. by Geoffrey H. Bourne, New York
and London: Academic Press, Inc., 1963.

Design and instrumentation for a successful weightlessness simulator are discussed in terms of the three major effects it must produce: (1) deprive the subject of all important sensory cues (visual, mechanical, balance) to the existence of a gravitational field; (2) produce as many as possible of the important physical and physiological effects (on vestibular function, respiration, diurnal rhythms, locomotion, manipulation skill, muscle, bone, and cardiovascular function, cause motion sickness) of a true gravity-free state; and (3) appeal psychologically (exhilaration, isolation, physical contact loss) to the subject as a true representation of actual space flight conditions in as many modes as possible. The Lockheed null-gravity simulator gives promise of fulfilling these conditions. It consists of a large tank filled with water in which the subject is immersed; the tank and its contents are rotated rapidly at a constant speed. Basic experimental procedures in using the simulator (subject fitting, positioning system, breathing air system), and safety measures are discussed.

93. Levine, R. B.
NEW APPROACH TO ZERO GRAVITY TESTS.
Aircraft & Missiles, 4:26–29, Jun 1961.

In order to simulate the environment, Lockheed's Null-Gravity Simulator utilizes the process of immersing a man in water. Water immersion gives the following desired effects: (1) the subject loses the ability to detect gravitational support, (2) muscular effort for maintaining posture is reduced, (3) previously stretched, soft tissues no longer perceive the direction and magnitude of the gravitational field, (4) the force of friction between the vessel walls and the subject decreases to zero, and (5) hydrostatic pressures in the circulatory system are nearly equaled by the water pressure. Also included is a physical description of the simulator.

94. Man in Sea Helps Space Research.
UNDERSEA TECHNOLOGY, 6(3):16, Mar 1965.

General Electric uses the facilities of Philadelphia's Aquarama to simulate weightlessness in tests of man working at consoles of its version of the MOL.

95. Seeler, Henry W.
UNDERWATER PRESSURE-COMPENSATED BREATHING CONTROL VALVES FOR PROLONGED WATER IMMERSION. Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio. Final Rept. for Feb 1960 – Jun 1962, AMRL-TR-64-130. AD-611 807.

Two water-pressure-compensated breathing devices for prolonged immersion have been designed, fabricated, and tested underwater. One valve is a continuous-flow regulator and the other is a demand regulator. Both valves allow exhalation through a hose directly into the surface atmosphere for air analysis. One of the two valves has been used extensively during prolonged weightlessness simulation tests by immersion.

96. WEIGHTLESSNESS – UNDERWATER FOR OUTER SPACE.
Product Engineering. 52, 4 Jan 1965.

A brief article on underwater studies made by Boeing Company, Seattle, Washington. The test chamber used is 15 ft deep, 19 ft long and 14 ft wide, big enough to test mockups of proposed space vehicles. The research program is OGER (O-Gravity Effects Research).

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13. ABSTRACT

This compilation contains 97 selected references pertaining to biomedical and behavioral research involving immersion of human subjects. The references are organized under three principal topics: (1) Physiological Studies, including acceleration, impact protection and physiological responses to weightlessness simulations, (2) Human Engineering Studies, and (3) Techniques and Personal Equipment Requirements for immersion studies.

The references are arranged alphabetically by author or title under each separate topic. An Author Index is included as an aid in locating specific investigators and publications.

The references cited are considered to be the principal contributions to the literature during the period from 1951 through July 1965, including both open and government sources.

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